International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249-6890; ISSN (E): 2249-8001
Vol. 8, Issue 3, Jun 2018, 193-202

OPTIMIZATION OF STACKING SEQUENCE OF COMPOSITE CYLINDRICAL SHELLS USING GENETIC ALGORITHM

MALLIKARJUN. J[1], P. NAGA SAI TEJA[2], G. BHARADWAJ SUBBA RAJU[3], N. SAI JAGANNADH[4] & J. AKHIL GUPTA[5]

[1]*Assistant Professor, Department of Mechanical Engineering, KLEF, Guntur, India*
[2,3,4&5]*Student, Department of Mechanical Engineering, KLEF, Guntur, India*

ABSTRACT

Optimization of stacking sequence would enable the designer to efficiently exploit tailoring abilities of such filament wound cylinders. Hence, the main aim of the paper was to perform optimization of stacking sequence using a genetic algorithm for two representative models with the first model having a length of 1650 mm and diameter 350 mm and second model with length 238 mm and diameter 184 mm. MATLAB programs for calculating critical buckling pressure (CBP), stiffness matrix and fitness evaluation function were developed using Sander's type analytical model. Then, the parametric study was performed to investigate the effect of geometrical dimensions on CBP, determine optimum settings for MATLAB Genetic Algorithm (GA) toolbox and a number of elements for performing Eigen buckling analysis in ANSYS. Considering the optimal parameters, optimization of stacking sequence using MATLAB GA tool for increasing depth of operation of both the models and decreasing weight of the first representative model was performed. The parametric study indicated that CBP is inversely proportional to (5/2)th power of D/t ratio and first power of L/D ratio. The CBP was maximized for a stacking sequence that leads to the dimensionless bending stiffness ratio nearly equal to 0.1. Thicknesses of the full-scale models of first representative cylinders were 13.2 mm and 18 mm of carbon/epoxy and glass/epoxy respectively for a depth of operation of 1000 m. CBP of the second model with a thickness of 5 mm was 16 MPa and 7.8 MPa for carbon/epoxy and glass/epoxy respectively. For the first model, substantial improvements of over 85 % and 44 % in depth of operation for carbon/epoxy and glass/epoxy were achieved, weight reductions of 13 % to 23.4 % for an operating depth of 1000 m were achieved. For the second representative model, improvements of 52.36 % and 19 % in depth of operation for carbon/epoxy and glass/epoxy respectively were achieved. A deviation of 5 – 25 % and 10 – 40 % was observed for glass/epoxy and carbon/epoxy respectively when compared with results obtained from Eigen buckling analysis using ANSYS.

***KEYWORDS:** CBP (Critical buckling pressure), ANSYS 14.5 & Matlab*

Received: Mar 14, 2018**; Accepted:** Apr 04, 2018**; Published:** Apr 28, 2018**; Paper Id.:** IJMPERDJUN201822

INTRODUCTION

Optimization of composite structures Use of composite materials has been growing in many fields due to their high specific strength, high specific stiffness and their ability to be tailored to particular applications, in particular the aerospace and submarine applications. Recently, the use of composite materials for underwater vehicles was recommended in many designs [1-4]. This growing use of fiber reinforced composite laminates, has called for optimization of composite laminate design which will enable effective use of tailoring capabilities of composite structure. Structural optimization is a multi-step procedure starting from global multi-disciplinary optimization to a local mono disciplinary optimization [5]. The global optimization results in determination of

optimal geometrical dimensions and best material for the structure. The detailed mono-disciplinary optimization involves determining optimum solutions to the local design problems. Over the past three decades a lot of research has been focused on optimizating for the minimum weight of composite structures, which was achieved by minimization of geometrical dimension such as thickness subjected to strength and stability constraints [6-9]. Generally, in case of composite structures the orientation of plies was fixed while performing minimization of thickness due to manufacturing constraints. The orientation of each ply was fixed to one or combination of 90°, ±60°, ±55°, ±45° filament winding angles [10-12]. With the recent developments in composite manufacturing science and technology, the range of allowable ply angles can now be increased. For the optimal thickness determined during global optimization, the stability limit of the structure can further be increased by exploiting the influence of stacking sequence of critical buckling loads [13] as well as natural frequency [14]. The optimization of fiber reinforced composite structures can broadly be classified as minimization of thickness, maximization of stability limit and maximization of natural frequencies. One particular work by [15] involves optimization for maximization of ultimate strength, which would be required for designing thick shells. Also, combinatorial optimization procedures involving maximization of buckling load with minimization of weight have also been performed Le Riche et al.in their paper [16] proposed a procedure for optimization of stacking sequence of a simply supported graphite/epoxy composite plate subjected to axial compressive loads considering buckling, contiguity as well as strain constraints. N Kogiso et al.in their paper [17] had indicated that stacking sequence optimization becomes a non-linear problem when strength constraints are considered and reported a methodology to solve the stacking sequence optimization problem for buckling load maximization considering 0°, 90° and ±45° ply angles. G Soremekun et al. in their paper [18] optimized a simply supported graphite/epoxy composite plate with 20 in. length and 10 in. width subjected to axial compressive loads.A Todoroki et al. in their paper [19] optimized stacking sequence of composite cylinder under axial compression loading subjected to contiguity, angle difference and balance constraints and proposed a procedure to improve the design reliability and reported a substantial increase in the design reliability. T Messager et al [10] optimized stacking sequence of thin cylindrical vessel subjected to external hydrostatic pressure considering 30°, 45°, 60°, 75° and 90° orientations and then by coupling the developed analytical buckling model with a genetic algorithm procedure. The authors reported stability gains of more than 35 % compared to ±55° reference cylinders. The authors validated their research by conducting experiments on glass/epoxy composite cylinder and carbon/epoxy composite cylinder. The most popular method used for stacking sequence optimization is the genetic algorithm followed by simulated annealing [20]. These direct search methods despite of a low convergence rate than the gradient-based methods are widely used because of their ability to be not get stuck in a localoptima [24]. The optimization procedures in most of the previous researches reviewed here are performed using GA. The GA is a direct search algorithm based on the working of natural selection and natural genetics. GA involves selection of the fittest among string structures and subjecting them to structured yet randomized information exchange to form a search algorithm that efficiently searches historical information to speculate on new search points with an expected improved performance. Since the ply orientations are limited to a small set of angles due to manufacturing constraints and the ply thicknesses are limited to integer multiples of lamina thickness [16-23]. The optimization process becomes constrained, integer programming optimization problem which can be easily handled by GA. Review of literature [1-24] indicated that most of the researchers used in-house GA code for optimization which involved tedious efforts and yet did not produce accurate results and hence, various reinforcement techniques were proposed for improving the efficiency of the algorithm.

ANALYTICAL BUCKLING SHELL MODEL

Genetic Algorithm

Genetic Algorithm (GA) was used for performing the optimization process in the present work which is a search algorithm based on the working of natural selection and natural genetics. GAs involves selection of fittest among string structures and subjecting them to structured yet randomized information exchange to form a search algorithm that efficiently searches historical information to speculate on new search points with an expected improved performance.

Table 1: Dimensions of Representative Models

Representative Model	Scale	Diameter (mm)	Length (mm)
1	1:1	Di = 350	1650
	1:2	Di = 175	825
2	1:1 t = 5 mm	Do = 184	238

Table 2: Material Properties

Properties	Carbon/epoxy	Glass/epoxy
E1	156000 (MPa)	45600 (MPa)
E2	9650 (MPa)	16200 (MPa)
G12	5470 (MPa)	5830 (MPa)
ν12	0.28	0.278

Buckling Load Calculation using Analytical Model

A MATLAB code for CBP calculation using sander's type analytical model based on first order shear deformation theory was developed. The developed code was used to calculate stiffness-matrix, CBP, and fitness value for GA toolbox. Methodology for CBP calculation using analytical code is shown in Figure 1. The minimum of Eigenvalues determined corresponds to CBP of the structure considered.

Optimization using MATLAB GA Toolbox

MATLAB GA toolbox is used for optimization of stacking sequence for buckling load maximization. The mechanical and geometrical properties except forthe stacking sequence of the composite cylinder are to be entered into the analytical code developed since the optimization software should handle only one design variable which in this case is the stacking sequence of composite cylinder. The analytical code is saved with the filename OPTIMALSTACKING. The methodology for optimization of stacking sequence for buckling load maximization is shown in Figure 1.

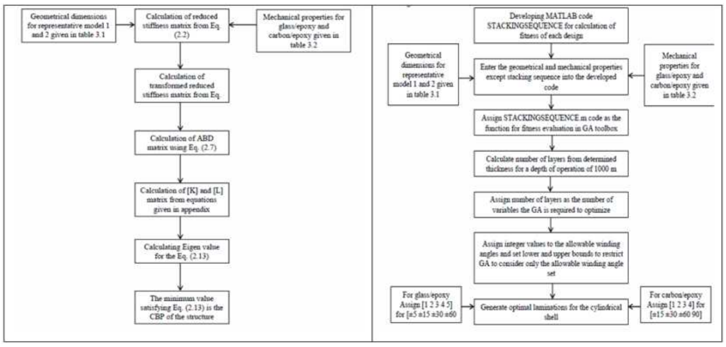

Figure 1: Methodology for Optimization of CBP Calculation using Analytical Code and Stacking Sequence

Buckling Analysis Using ANSYS

The analytical buckling shell model was validated with FEA results using ANSYS 14.0. The analytical and numerical results were generated for two different lengths and a range of thickness. These results were then compared graphically to establish the dependability on the developed analytical model. Methodology for buckling analysis of composite cylinders is shown

PARAMETRIC STUDY

Analytical Parametric Study of CBP

Unlike pressure vessels subjected to internal pressure, the designer has to consider other factors while designing an unstiffened cylindrical vessel subjected to external hydrostatic pressure. Apart from the thickness of the cylinder other factors that affect the design are diameter to thickness(D/t) ratio and length to diameter (L/D) ratio. An analytical parametric study was performed to investigate the influence of these parameters on CBP. Two commonly considered FRP-composite materials for pressure hull designs are glass/epoxy and carbon/epoxy composites. The material properties considered is given in Table 4. The effect of D/t and L/D ratios on critical buckling pressure are represented using a three dimensional graph shown in Figure 2 and 3 for glass/epoxy and carbon/epoxy cylinders respectively. The graph can be considered for any thickness, with diameter and length varying, strictly for only studying the influence of these parameters. A careful review of the graph indicated that CBP was inversely proportional to (5/2)th power of D/t ratio and first power of L/D ratio. Higher buckling pressures can be achieved for higher thickness to diameter ratio and lower length to diameter ratio.The above conclusions were same for both the materials considered. Fora given thickness, the diameter, and length of the cylinder has to be minimized for maximum stability and the selection of diameter and length usually is guided by the minimum volume required to install any equipment, which the UUV has to carry to perform the undertaken tasks. The two representative models were designed for two different applications. Depending upon their respective application the model diameters were to be realized as shown in Table 3. The variation in other diameters was due to floating thickness of the cylindrical shells. The thickness of the first representative model was increased from 3 mm up to 20 mm and the thickness for an operating depth of 1000 m was obtained

Table 3: Fixed Diameters for the Representative Models

Representative Model	External Diameter	Mean Diameter	Internal Diameter
1	Varying	Varying	Fixed at 350 mm
2	Fixed at 184 mm	Varying	Varying

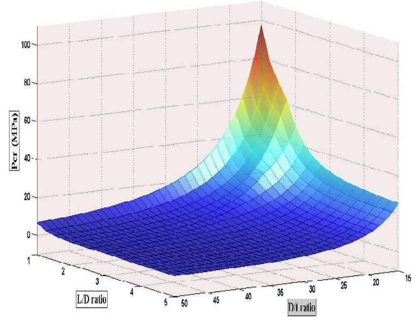

Figure 2: Parametric Study of Glass/Epoxy Cylinder

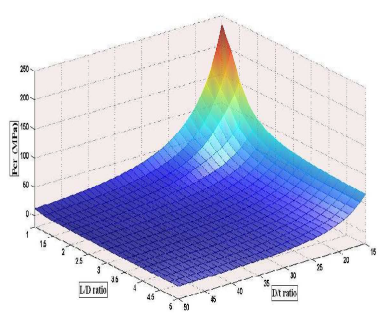

Figure 3: Parametric Study of Carbon/Epoxy Cylinder

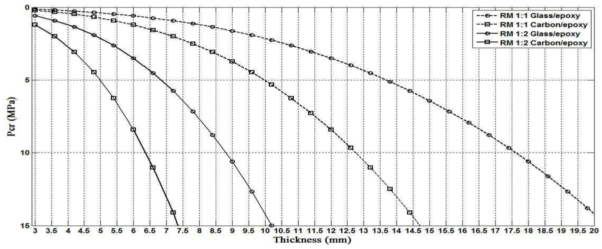

Figure 4: Influence of Thickness on CBP for Representative Model 1

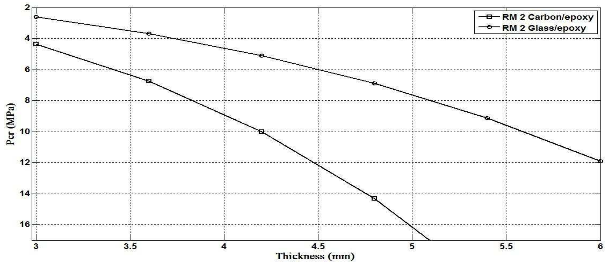

Figure 5: Influence of Thickness on CBP for Representative Model 2

The thickness of the representative model 1 was determined by varying the thickness over a fixed internal diameter as shown in Figure 4. Thickness for an operating depth of 1000 m was determined which are given in Table 4. The thickness of 1:2 scale model followed the same scaling factor of 0.5 with respect to 1:1 scale model.

Table 4: Calculated Thickness For Representative Model 1

Model scale	Material	Calculated Thickness (mm)
1:1	Carbon/epoxy	13.2
1:2	Carbon/epoxy	6.6
1:1	Glass/epoxy	18
1:2	Glass/epoxy	9

Table 4 Calculated thickness for representative model 1The increase in CBP for representative model 2 for increasing thickness is shown in Figure 5. The CBP for a thickness of 5 mm was 16 MPa and 7.8 MPa for carbon/epoxy and glass/epoxy respectively.

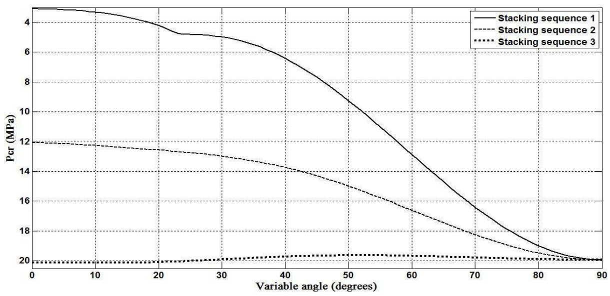

Figure 6: Critical Buckling Variations for Carbon/Epoxy Reference Model 1 (1:1 Scale)

Figure 6 Critical buckling variations for carbon/epoxy reference model 1 (1:1 scale) Influence of stacking sequence on CBP was studied considering full scale model of first representative cylinder and second representative model. Three types of stacking sequence were considered for the study Stacking sequence 1 [θ10], Stacking sequence 2

[(90/θ)5] and Stacking sequence 3 [903/θ4/903] with θ as the variable angle. Both Carbon/epoxy and glass/epoxy -cylinders were considered for the study. The graph showing evolution of CBP for representative model 1 made of carbon/epoxy cylinder and glass/epoxy cylinder is given in figure 6 and 7 respectively. The evolution of CBP for representative model 2 with carbon/epoxy cylinder and glass/epoxy is given in Figure 8 and 9 respectively.

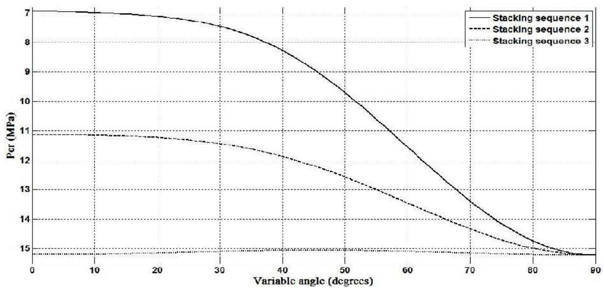

Figure 7: Critical buckling Variations for Glass/Epoxy Reference Model 1 (1:1 Scale)

The variations in stability were distinct for different stacking sequence considered. A maximum stability was observed for stacking sequence 3 for both the materials considered. The stability limit was found to be maximized for dimensionless bending stiffness ratio nearly equal to 0.1. And minimum stability was observed for 100% polar winding [010]. Hence, presuming the stacking sequence while designing a composite cylinder would result in ineffective use of

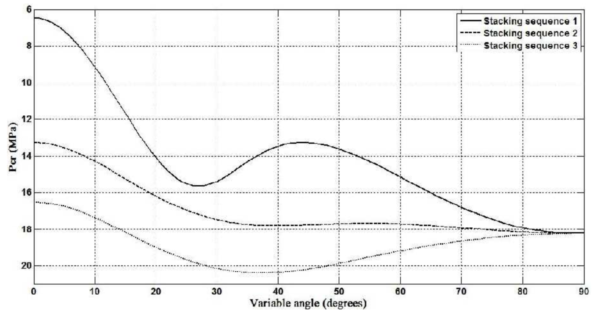

Figure 8: Critical Buckling Variations for Carbon/Epoxy Reference Model 2

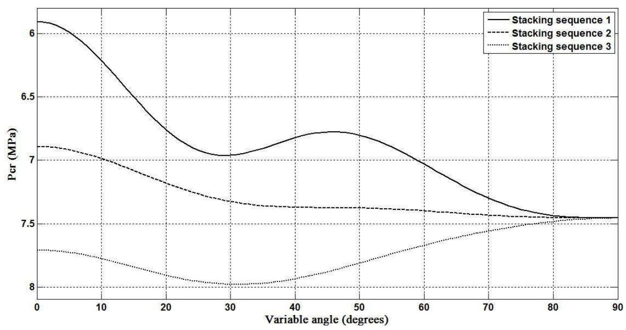

Figure 9: Critical Buckling Variations for Glass/Epoxy Reference Model 2

Tailoring capability of composites. And the selection of proper stacking sequence will considerably improve the stability of a composite cylinder.

Optimization for Maximum Buckling Load

Optimization of stacking sequence for a structure was performed by fixing the geometrical dimensions to increase it's CBP and hence further increase its depth of operation. The allowable winding angles for optimization procedure are {±15;±30;±60;90} and {±5;±15;±30;±60;90} for carbon/epoxy for glass/epoxy respectively. The depth of operation was calculated for each model by using Eq. (6.1).

$$H = \frac{CBP}{\rho g}$$

Where CBP is the critical buckling pressure of the structure considered, ρ = 999.97 kg/m³ is the density of water and g = 9.8 m/s² is the acceleration due to gravity. The optimization results are tabulated in Table 5 and 6 for first representative model and second representative model respectively, along with a comparison of depth of operation with the respective reference structures. The optimal laminations for all the combinations always resulted in [90A/±θB/90C] where ±θ is the minimum allowable angle. The corresponding CBP of optimized and reference structures were calculated using the analytical function critical buckling.

Table 5: Optimization for Maximizing Depth of Operation for First Representative Model

Model scale	Optimal laminations	Depth of Operation (optimized)	Depth of Operation ([±55°N])	Operating Capability Gain
Carbon/epoxy				
1:1	[909/±154/30/908]	2082 m (20.4 MPa)	1124 m (11.02 MPa)	85.23 %
1:2	[904/±153/904]	2081 m (20.38 MPa)	1124 m (11.02 MPa)	85.14 %
Glass/epoxy				
1:1	[9013/±55/9012]	1566 m (15.35 MPa)	1082 m (10.6 MPa)	44.73 %
1:2	[906/±53/906]	1566 m (15.35 MPa)	1082 m (10.6 MPa)	44.73%

Table 6: Optimization for Maximizing Depth of Operation for Second Representative Model

Model	Optimal laminations	Depth of Operation (optimized)	Depth of Operation ([±55°N])	Operating Capability Gain
t = 5 mm				
Carbon/epoxy	[902/302/±152/902]	2223 m (21.79 MPa)	1459 m (14.3 MPa)	52.36 %
Glass/epoxy	[902/±302/±52/902]	838 m (8.21 MPa)	704 m (6.9 MPa)	19 %

Substantial improvements in depth of operation of over 85 % increase for carbon/epoxy material and over 44 % for glass/epoxy material was achieved for the first representative model. Improvement of 52.36 % and 19 % was achieved for carbon/epoxy and glass/epoxy respectively for second representative model.

Optimization for Minimum Weight

Optimization for minimum weight was performed by optimizing cylinders with decreasing thickness till the minimum thickness required to bear a hydrostatic pressure of 9.8 MPa was reached. Optimization results for representative

model 1 are given in Table 7. The optimized weight were compared with the weight of the reference cylinders and corresponding decrease in weight was calculated. Weight reductions of 13.94 % to 23.4 % were achieved for the -corresponding structures.

Table 7

Material	Model	Weight (Kg) Reference Cylinders [±55°N]	Weight (Kg) Optimized Cylinders	Decrease in weight (%)
Carbon/epoxy	1:1	8.76	6.71	23.40
	1:2	1.09	0.89	18.35
Glass/epoxy	1:1	13.2	10.91	17.42
	1:2	1.65	1.42	13.94

RESULTS AND DISCUSSIONS

Eigen buckling analysis of optimized cylinders

The new analysis was carried out by changing to Eigen-buckling analysis. The buckling mode was set to three using ‘Block Lanczos’ and the load step option was also set to three, which would give three lowest buckling pressures

Table 8

Representative model	Analytical Results	Eigen buckling Results
Carbon/epoxy		
1 (full scale model)	20.4	13.21
1 (1:2 scale model)	20.38	13.68
2	21.79	18.2
Glass/epoxy		
1 (full scale model)	15.35	11.86
1 (1:2 scale model)	15.35	11.87
2	8.21	8.2

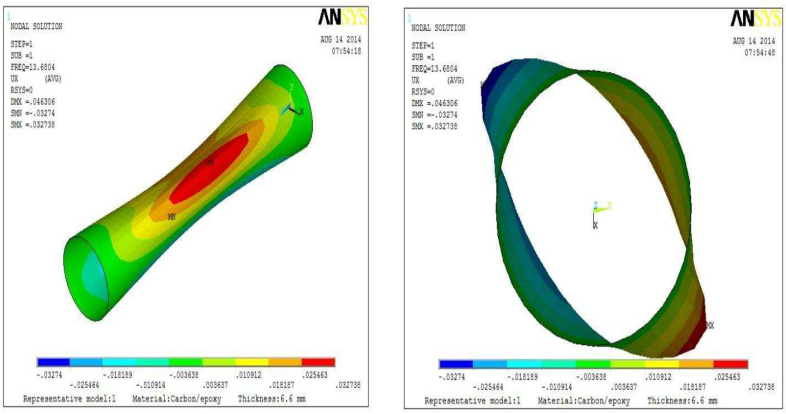

Figure: 10

After the solution is done, the buckling pressure for the first three buckling loads could be observed in result summary. The lowest of the values were recorded and tabulated in Table 8. The buckling mode shape of the cylinder can be obtained by graphically plotting the eigen mode. The CBP can be obtained from the result summary table or from the graphical plot of the eigenmode, which is given a frequency value. Figure (e) and (f) shows buckled first representative model in two perspectives. The comparison of analytical and numerical results are tabulated in Table 8 Figure FEA using

ANSYS (a) Modeling (b) Meshed model (c) Layers (d) Applying boundary condition and pressure (e) Buckled cylinder (f) Front view of the buckled cylinder

CONCLUSIONS

Numerical analysis of optimized cylinders was performed and compared with analytical results. Based on all the works performed The parametric study indicated that stability limit of composite cylinders is inversely proportional to 2.5th power of D/t ratio and first power of L/D ratio. The critical buckling was maximized for a stacking sequence that leads to the dimensionless bending stiffness ratio nearly equal to 0.1Thicknesses of first reference cylinder were 13.2 mm and 18 mm for carbon/epoxy and glass/epoxy cylinders respectively to operate at a depth of 1000 m. A population size of 100 and an elite count of 10 % to 50 % of the population size in MATLAB GA toolbox settings produced more accurate optimal solutions. A minimum of1000 elements are required to generate sufficiently accurate results in ANSYS FEA software. For the first representative model, substantial improvements of over 85 % and over 44 % in-depth of operation for carbon/epoxy and glass/epoxy respectively were achieved. And weight reductions of 13 % to 23.4 % were achieved for the structures considered. For the second representative model, improvements of 52.36 % and 19 % in depth of operation for carbon/epoxy and glass/epoxy respectively were achieved.

REFERENCES

1. *Robert M. Jones, "Mechanics of Composite Materials", Taylor & Francis Group, 2nd edition,1999.*
2. *C. S. Smith. "Design of Submersible Pressure Hulls in Composite Materials". MarineStructures (1991) 141-182.*
3. *Derek Graham. "Composite pressure hulls for deep ocean submersibles". CompositeStructures 32 (1995) 331-343.*
4. *Carl T. F. Ross. "A conceptual design of an underwater vehicle". Ocean Engineering 33(2006) 2087-2104.*
5. *Francois-Xavier Irisarri, David Hicham Bassir, Nicolas Carrere, Jean-Frncois Maire."Multiobjective stacking sequence optimization for laminated composite structures". Composites Science and Technology S0266-3538(09)00007-4.*
6. *L A Schmit and B Farshi. "Optimum design of laminated fiber composite plates". International journal for numerical methods in engineering, Vol. 11, 623-640 (1977).*
7. *Vladimir B Gantovnik, Zafer Gurdal, Layne T Watson. "A genetic algorithm with memoryfor optimal design of laminated sandwich composite panels". Composite Structures 58(2002)513-520.*
8. *Vladimir B. Gantovnik, Christine M. Anderson-Cook, Zafer Gurdal, Layne T. Watson. "Agenetic algorithm with memory for mixed discrete-continuous design optimization". Computers and Structures 81 (2003) 2003-2009.*
9. *Chung Hae Park, Woo Il Lee, Woo Suck Han, Alain Vautrin. "Improved genetic algorithm for multidisciplinary optimization of composite laminates". Computers and Structures 86(2008) 1894-1903.*
10. *Tanguy Messager, Mariusz Pyrz, Bernard Gineste, Pierre Chauchot. "Optimal laminations ofthin underwater composite cylindrical vessels". Composite Structures 58(2002) 529-537.*
11. *H. Hernandez-Moreno, B. Douchin, F. Collombet, D. Chosqueuse, P. Davies. "Influence ofwinding pattern on the mechanical behavior of filament wound composite cylinders under external pressure". Composites Science and Technology 68 (2008) 1015-1024.*
12. *Chul-Jin Moon, In-Hoon Kim, Bae-Hyeon Choi, Jin-Hwe Kweon, Jin-Ho Choi. "Buckling offilament-wound composite cylinders subjected to hydrostatic pressure for underwater vehicleapplications". Composite Structures 92 (2010) 2241-2251.*

13. *B.Geier, H-R. Meyer-Piening, R. Zimmermann. "On the influence of laminate stacking onbuckling of composite cylindrical shells subjected to axial compression". CompositeStructures 55 (2002) 467-474.*

14. *M Kemal Apalak, Mustafa Yildrim, Recep Ekici. "Layer optimisation for maximumfundamental frequency of laminated composite plates for different edge conditions".Composite science and technology 68 (2008) 537-550.*

15. *J. H. Park, J. H. Hwang, C. S. Lee, W. Hwang. "Stacking sequence design of compositelaminates for maximum strength using genetic algorithm". Composite structures 52 (2001)217-231.*

16. *Gaur, Akanksha, Priyanka Wadhwani, and Vipin Jain. "Secured Steganography Model using Genetic Algorithm."*

17. *Rodolphe Le Riche, Raphael T. Haftka. "Optimization of laminate stacking sequence forbuckling load maximization by genetic algorithm". AIAA journal, Vol. 31, No. 5, May 1993,pp. 951-956.*

18. *Kogiso N, Watson LT, Gurdal Z, Haftka RT. "Genetic algorithm with local improvement forcomposite laminate design". Structural Optimization 1994; 7:207–18.*

19. *G Soremekun, Z Gurdal, R T Haftka, L T Watson. "Composite laminate design optimizationby genetic algorithm with generalized elitist selection". Computers and Structures 79(2001)131-143.*

20. *Girgis, Moheb Ramzy, Abdelmgeid Amin Aly, and Fatima Mohy Eldin Azzam. "The Effect of Similarity Measures on GENETIC Algorithm-based Information Retrieval."*

21. *Akira Todoroki, Masahumi Sasai. "Improvement of design reliability for buckling loadmaximization of composite cylinder using genetic algorithm with recessive-gene-like repair".JSME International Journal, Series A, Vol. 42, No. 4, 1999, pp. 530-536.*

22. *Hossein Ghiasi, Damino Pasini, Larry Lessard, "Optimum stacking sequence design ofcomposite materials Part I: Constant stiffness design". Composite Structures (2009).*

23. *Raphael T Haftka, Joanne L Walsh. "Stacking sequence optimization for buckling oflaminated plates by integer programming". AIAA journal, Vol. 30, No. 3, Mar 1992, pp. 814-819.*

24. *S Nagendra, Raphael T Haftka, and Z Gurdal. "Stacking sequence optimization of simplysupported laminates with stability and strain constraints". AIAA journal, Vol. 30, No. 8,August1992, pp. 2132-2137.*

25. *Boyang Liu, Raphael T Haftka, Mehmet A Akgun, Akira Todoroki. "Permutation geneticalgorithm for stacking sequence design of composite laminates". Computational methods inapplied mechanics and engineering, 186 (2000) 357-372.*